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Microstructural Aspects of Incorporation of Manganese Slag in Modified Brick as Sustainable Construction Materials

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ABSTRACT

Scanning Electron Microscope (SEM) observations of using slag resulted in more noticeable microstructure with gaps as the higher percentage of manganese slag incorporated in the modified brick. Therefore, the analysis using SEM emphasizes the optimal proportion is required when integrating slag into the production of bricks. Utilizing proportion up to 20% could present an approach for environmentally friendly brick making while minimizing the negative influence on structural strength. This contributes to reactivity and leads to the formation of C-(A)-S-H and ettringite which finally creates a denser structure. However, the similarities of all of these research are when the slag usage is higher than 20%, the pores is more significant.

1. Introduction

Sustainable materials are typically derived from renewable resources or are capable of being recycled or utilised without significant quality or value loss. This reduces the demand for new resources and refuse production. Besides that, high durability, long-lasting, and abrasion-resistant are all characteristics that are needed to be present in sustainable materials [5,7]. This helps lessen the need for frequent replacement and prolong the usable life of the product, which in turn helps reduce the amount of resources used and the amount of waste generated. In terms of environmental sustainability, sustainable materials aim to minimise greenhouse gas emissions and waste generation.

Bricks that have been altered or designed in such a way as to contain certain features or characteristics beyond or same as those of ordinary bricks are referred as modified bricks. This is often done in order to improve the performance, durability, energy efficiency, or aesthetic appeal of

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the bricks. But, nowadays the crucial reason of why bricks being modified with sustainable material because it can contribute to the overall sustainability of building projects by lowering resource consumption, minimising waste creation, and mitigating the negative impact of construction to the environment [2,15,17,18] while preserving its performance and usefulness.

In the present time, there are many producers of concrete brick, and developers opt for concrete brick due to the high cost of conventional brick. Thus, incorporating the sustainable material such as slag and other by-product is one of the reliable excellent alternatives. This statement is supported by [7] that reported the addition of by product which are slag and fly ash resulted in a significant increase in both the strength and durability of the cementitious materials as well as an improvement in the material's resistance to water absorption and chloride migration.

Incorporating manganese slag into building materials such as brick is a sustainable solution since it repurposes an industrial by-product, reduces resource consumption, and has the potential to improve performance. Therefore, in this research, the feasibility of incorporating manganese slag as a partial replacement for cement in brick production will be investigated.

Utilizing waste materials in bricks shows potential for improving sustainability in construction. Each material comes with its advantages and drawbacks underscoring the need to optimize their utilization according to application needs. Further studies should focus on refining these combinations to achieve performance with minimal harm to the environment.

2. Methodology

2.1 Preparation of Material

This part discussed the ingredients employed in creating the modified bricks. The key components consist of Ordinary Portland Cement (OPC), sand, manganese slag and water. Each of these elements has an impact, on defining the characteristics and effectiveness of the end result.

2.2.1 OPC

The primary binding agent chosen for brick production was Ordinary Portland Cement (OPC). OPC plays a role by providing calcium silicates that enhance the strength and durability of bricks during the hydration process. Its chemical composition comprises elements, like calcium oxide (CaO) silicon dioxide (SiO_2) aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) which collectively impact the setting time strength development and overall performance of the bricks. The Ordinary Portland Cement (OPC) that were used in this research possess the strength class of 42.5 N/mm^2.

2.2.2 Sand

The mix design included aggregate, which was natural river sand. Sand plays a role in providing volume, strength and stability to the cement matrix [19]. In this study the sand underwent sieving to eliminate impurities. The gradation of sand particles influences the workability, density and compressive strength of bricks [5]. The natural river sand used was sieved to pass through a 4.75 mm sieve to ensure uniform particle size distribution and to enhance the workability and strength of the final mix.

2.2.3 Manganese slag

The type of manganese slag that will be used in this research is wet manganese slag. The manganese slag was obtained from Pertama Ferroalloys Sdn Bhd company which located at Similajau, Bintulu, Sarawak (Figure 1).

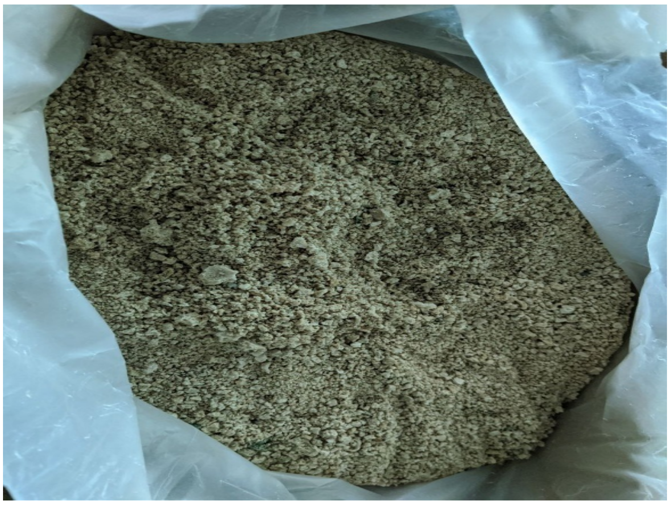

Fig. 1. Manganese Slag from Pertama Ferroalloy

2.2.4 Water

Water is an essential component in the mix design, playing a key role in the hydration process of cement. The water used in this study was potable and free from any contaminants that could adversely affect the setting time or strength of the cement. The water-to-cement (w/c) ratio was carefully controlled to achieve the desired workability and consistency in the mix.

2.3 Mixing and Moulding

In this section, the design mix and the brick casting process will be further discussed. The design mix for brick casting was meticulously developed to achieve the desired properties, including optimal strength, durability, and workability. Next, the brick casting process was carried out in several stages to ensure the production of high-quality bricks with uniform properties.

2.3.1 Design mix for brick casting

The ratio of the design mix was established through experiments and research readings to achieve a balanced blend of Ordinary Portland Cement (OPC) sand, manganese slag and water. The proportions of the mix were determined based on volume with OPC serving as the binding agent, sand, as the aggregate and manganese slag as a substitute, for conventional fine aggregates

Based on Table 1, the samples were mixed in the cement-sand ratio of 1:2.5. Each mixture with different percentage of manganese slag has a total of 15 specimens; 9 specimens were assessed for compressive strength on days 3, 7, and 28, with 3 brick samples being evaluated on each of those days; 3 samples were evaluated for flexural strength on day 28, the remaining 3 samples were evaluated on day 28 for density and water absorption.

Table 1
Design Mix

Cement: Sand	Sample Name	% of Sand Replacement with Manganese Slag	No. of Samples
1: 2.5	MS0 (Control)	0%	15
	MS20	20%	15
	MS40	40%	15
	MS60	60%	15
	MS80	80%	15
Total Number of the Samples			75

2.3.2 Brick casting

Brick specimens with 215 mm in length, 102.5 mm in width, and 65 mm in height were casted in a brick steel mould as shown in Figure 2.

Fig. 2. Steel Brick Mould

Initially, the dry materials, including OPC, sand, and manganese slag, were thoroughly mixed to achieve a homogeneous blend. Water was then gradually added to the dry mix while continuously stirring to avoid the formation of lumps and to ensure a consistent mixture. Each batch of mixture sample with were mixed with specific proportion as stated in Table 1. Before the cement paste were placed in the brick mould, the brick mould was greased at the inner part to ease the step of demoulding process.

The prepared mixture then was poured instantly into brick molds that had been greased with oil to prevent the material from adhering to the surfaces of the molds. Then, the desired mixtures were compacted by using a rod compacter with 25 strokes for three layers in the steel brick mould eliminate air pockets and ensure proper compaction.

After filling and compacting, the bricks were leveled off and smoothed to remove any excess material. The bricks were then allowed to set in the molds for 24 hours under controlled conditions before being demolded and transferred to a curing environment. Next, the specimens were removed from the moulds a day after the casting process.

During the demolding process, the bricks were gently separated from the molds. This required careful handling to avoid any damage to the edges or surfaces of the bricks, which could compromise their structural integrity. The molds were either opened or the bricks were gently pushed out using a demolding tool, ensuring that the bricks retained their intended shape and dimensions. After demolding, the bricks were placed on a flat surface in a controlled environment to undergo further curing. This curing phase was vital for the bricks to achieve their final strength and durability, as it allowed the cement's hydration process to continue, further enhancing the bricks' mechanical properties.

After demoulding, the samples were cured by being soaked in water tank for the desired duration which are (3, 14, 28 days) curing days respectively. The process of curing concrete is critically important for improving its durability and strength [12]. The strength and durability of concrete might be significantly impacted when the curing process is not carried out properly [8]. In order to reach the desired level of hydration and strength, conventional concrete must be allowed to cure for a minimum of 28 days [9].

2.4 Curing

Controlling the temperature as well as the flow of moisture out of and into the concrete is an essential part of the curing process, which is also known as "curing." Curing processes that are used in order to promote the hydration of the cement. Curing permits continual hydration of cement and, as a consequence, continuous growth in strength; nevertheless, once curing is terminated, strength gain in the concrete similarly comes to an end. The hydration of the cement nearly stops when the relative humidity inside the capillaries goes below 80%, maintaining the appropriate moisture levels is very essential. In inadequate moisture, the hydration process will not progress, and the concrete that is produced may not have the desired strength and impermeability [16].

In this research, the curing duration for each batch of the sample mix was set to 3, 7, and 28 days before the samples were taken out and tested for water absorption, density, compressive strength, and flexural strength of the modified concrete brick (Figure 3).

Fig. 3. The Concrete Brick Samples Cured in Curing Tank

After curing, the concrete bricks were measured in dimension before the testing for hardened properties take place. The dimensions were required to be within the parameters set out by BS 3921:1985 (Table 2).

Table 2
Limit of size (BS 3921:1985)

Work Size (mm)	Measurement of 24 bricks (mm)	
	Minimum	Maximum
215	5085	5235
102.5	2415	2505
65	1515	1605

2.5 Microstructural Analysis

In this research there were 2 types of microstructural test that have been conducted which are Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray (EDX). Figure 4 and 5 show the SEM and EDX Machine. The objective of the Scanning Electron Microscope (SEM) examination was to obtain high-resolution images of a sample's surface morphology and microstructure. SEM enables the visualisation of the sample's magnification in a great detail, providing information about its size, shape, and arrangement of [6,13,23].

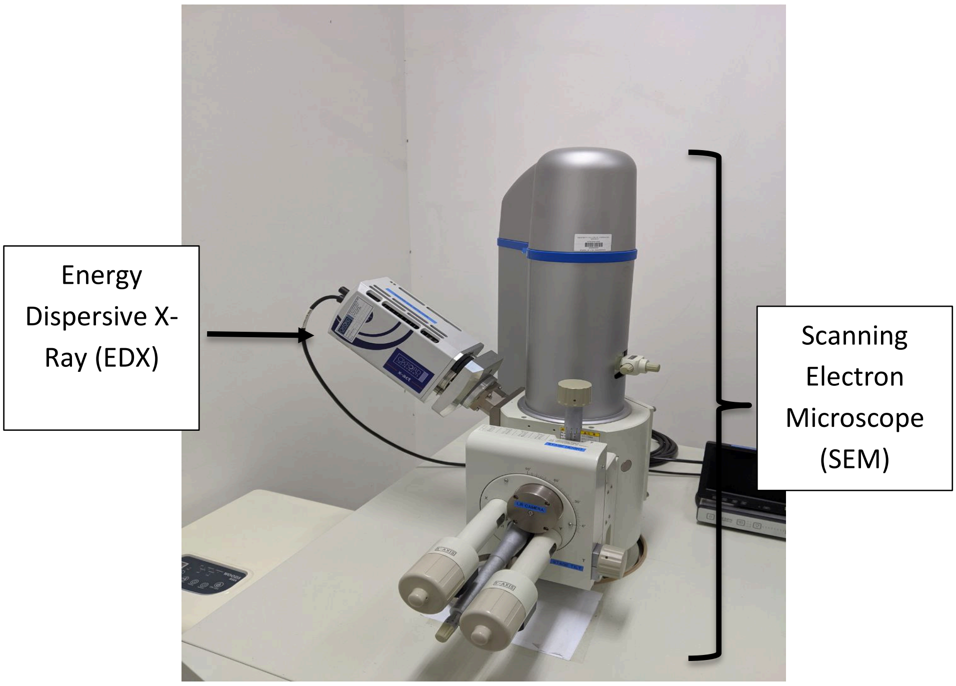

Fig. 4. SEM and EDX Machine in UTS Environmental Laboratory

Fig. 5. SEM and EDX Machine with Monitor to Visualize the Results of SEM and EDX

In contrast with SEM, the Energy Dispersive X-Ray (EDX) test, which was performed in conjunction with SEM, seeks to determine a sample's elemental composition. EDX analysis employed X-ray spectroscopy to identify and quantify the sample's elements. By monitoring the characteristic X-rays emitted when a sample was bombarded with electrons, EDX can determine a material's chemical composition [6,13,23]. This method was useful for identifying elements, determining their distribution within a sample, and analysing elemental concentrations in this research.

Therefore, SEM provides visual information about the surface morphology and microstructure of the sample, while EDX complements it by revealing the elemental composition and distribution.

Before the sample was tested by SEM and EDX machine, coating process was done to boost image quality, enhance contrast, preserve the sample surface, and promote accurate elemental analysis. Figure 6 shows the machine to coat the samples prior testing for SEM and EDX.

Fig. 6. Coating Machine

2.5.1 Scanning Electron Microscopy (SEM)

First, appropriate samples were chosen to analyse. This includes sample collection, cutting, and substrate mounting. The SEM instrument was then calibrated in accordance with the manufacturer's instructions to ensure accurate imaging and measurements. The imaging procedure begins with the use of reduced magnification settings to identify regions of interest and obtain a sample overview. The magnification is then progressively increased to capture high-resolution images of particular regions or characteristics. These SEM images were then analysed

2.5.2 Energy Dispersive X-Ray (EDX)

The samples (Figure 7) were carefully handled and then placed on appropriate holders to guarantee that they remain stable during the study. The scanning electron microscope (SEM) was calibrated in accordance with the manufacturer's instructions before it can be used for EDX analysis. This was done to ensure accurate readings and the best possible imaging. When performing an EDX examination, the electron beam was scanned over the surface of the sample, which causes the presence of distinctive X-rays to be produced from the elements that were present. After that, an energy-dispersive detector was used to detect and analyse the X-rays that were produced. After the spectra have been obtained, they were processed and analysed so that the chemical composition of the samples can be determined, and the elemental concentrations will be quantified.

Fig. 7. The Samples for SEM EDS Testing

3. Results

The stated results are systematically discussed. A comparison is drawn between control brick with different levels of manganese slag replacement (20%, 40%, 60% and 80%) to understand how manganese slag influences overall brick performance. By analyzing the data and comparing it with existing literature, this chapter provides a critical evaluation of the use of manganese slag in brick manufacturing. The results on the microstructural investigation of various proportion of sand replacement of manganese slag were determined after the sample has been cured for 28 days.

The results then were interpreted through suitable discussion based on the latest available theories. The SEM images were presented in Figure 8 to 12. The SEM images shown in this research exhibit the microstructural change of modified bricks as the amount of slag substitution rises. The reference sample having no replacement at 0% acts as a standard displaying a fairly uniform microstructure commonly found in bricks. With an increase in slag replacement percentage, noticeable change in the microstructure can be observed which cold impact the strength and the durability of the brick.

From Figure 8, the SEM image of the control sample shows a packed structure, with very few holes. This consistency suggests a connection between the cement materials and sand creating the better compressive strength than other percentage of replacement as can be seen in compressive strength results.

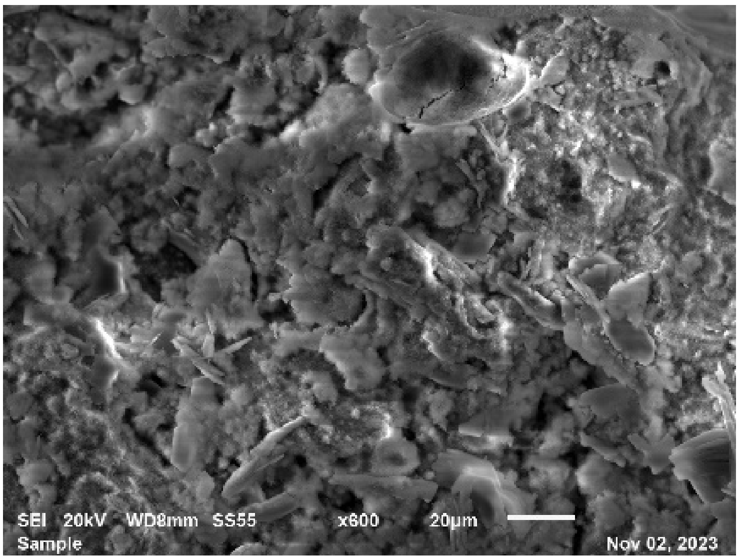

Fig. 8. SEM Image of Control

From Figure 9, when 20% of slag is used as a replacement the structure starts showing pores. The appearance of spaces implies a decrease in density and a possible weakening of the brick. However, with this alteration, the matrix seems to be fairly stable suggesting that substituting 20% of the material could still be considered acceptable for preserving brick durability.

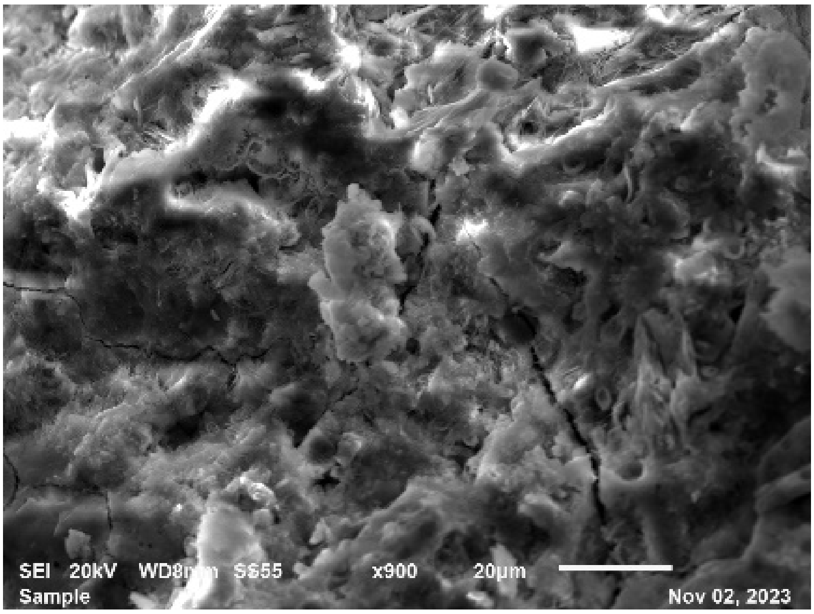

Fig. 9. SEM Image of MS20

From Figure 10, with 40% replacement there is an increase in porosity and a uniform structure. The presence of slag particles is more evident leading to empty spaces and an uneven distribution.

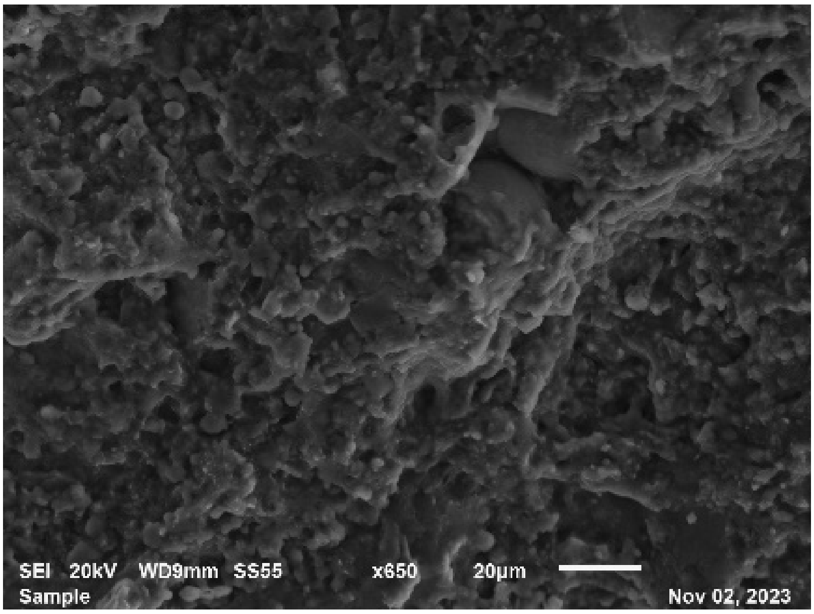

Fig. 10. SEM Image of MS40

From Figure 11 and Figure 12, the SEM image shows a porosity and fragmentation with noticeable gap in the matrix due to the high presence of manganese slag particles. The abundance of voids indicates a weakening of the bricks strength, at a 60% and 80% replacement rate. This extent of replacement implies that the bricks might have difficulty to bear loads [3] and could experience higher water absorption and decreased durability [20].

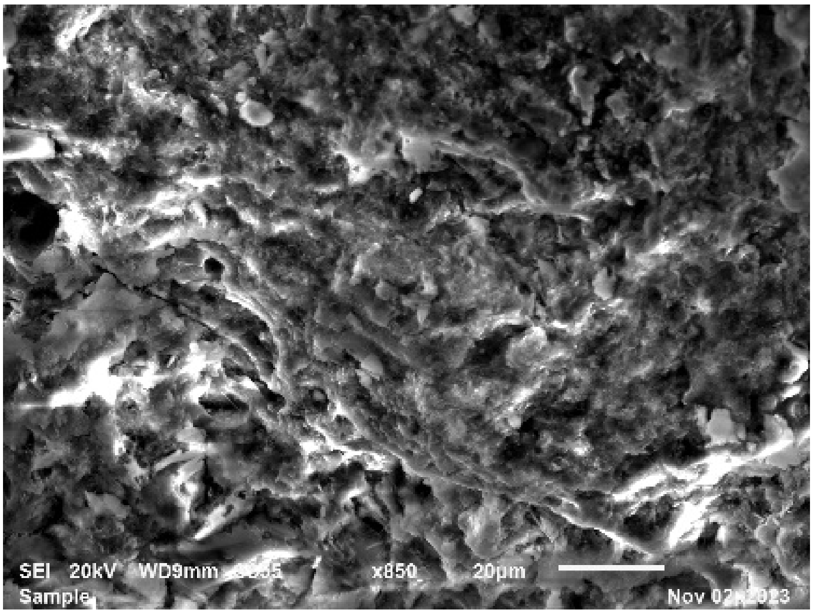

Fig. 11. SEM Image of MS60

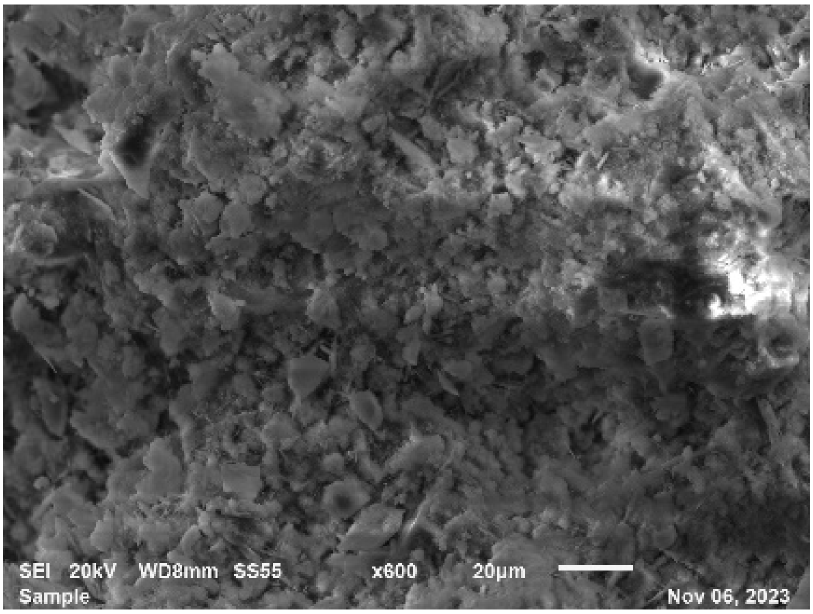

Fig. 12. SEM Image of MS80

Therefore, the analysis using SEM emphasizes the optimal proportion is required when integrating slag into the production of bricks. Utilizing proportion up to 20% could present an approach for environmentally friendly brick making while minimizing the negative influence on structural strength.

Similar results were observed by [1]. The study shows incorporating 20% copper slag aggregates (CSA) to self-compacting geopolymer concrete (SCGC) exhibiting superior microstructural characteristics and showed enhanced quartz and calcium silicate hydrate (CSH) formation. [14] stated that the usage of 20% air cooled blast furnace slag (BFS) as sand substitute in road concrete showed that the dense structure and lowest portlandite crystal content suggesting a more compact microstructure compared to another percentage of sand replacement. According to [11], the addition of slag in materials with red mud resulting in a higher silicon and aluminium content. This contributes to reactivity and leads to the formation of C-(A)-S-H and ettringite which finally creates a denser structure. However, the similarities of all of these research are when the slag usage is higher than 20%, the pores is more significant.

3.1 EDS Testing

This test is essential to interpret these findings to assess how manganese slag influences the microstructure of the modified cement bricks. The Energy Dispersive X-ray Spectroscopy (EDS) results of the control and another percentage of replacement samples (MS20, MS40, MS60 and MS80) show differences in composition. These variations indicate the there was an impact of adding manganese slag to the cement mix. The data table shows the percentage of each element found in the samples offering an insight about how the manganese slag incorporation in the modified brick influences the composition and the characteristics of the cement bricks.

Table 3
The Maximum Percentage of Each Element in Every Sample

Element	Control	MS20	MS40	MS60	MS80
C	13.87	7.52	11.19	6.92	11.42
O	66.41	49.11	77.28	50.92	38.24
Na	-	-	2.1	-	-
Mg	0.9	-	0.35	1.56	0.63
Al	3.36	2.37	4.84	3.73	3.52
Si	20.62	6.86	22.95	43.16	11.05
S	1.27	0.91	0.48	0.73	1.26
K	2.92	1.4	1.92	2.56	2.54
Ca	33.59	33.37	27.6	29.71	23.45
Fe	2.77	1.24	0.74	0.58	1.33
Mo	4.06	2.69	1.64	1.38	3.69
Sn	12.66	6.27	8.02	9.98	9.93
Sb	31.24	22.44	27.6	33.21	23.63
I	10.41	6.3	6.2	6.95	5.91

Carbon (C); The sample, without any modifications has the carbon content at 13.87%. This decreases notably in the changed samples especially in MS20 (7.52%) and MS60 (6.92%). This decrease is likely due to adding slag. Similarly, [10] also found out that the higher the slag incorporated, the lower the carbon content will be.

Oxygen (O); The levels of oxygen vary significantly among the samples with the control sample having 66.41% and highest at 77.28% in MS40. These fluctuations are probably because of substances forming during the cement curing process. The higher oxygen content in MS40 indicates formation of substances like calcium silicate hydrate (C-S-H) [21] which is essential for the concrete mechanical strength.

Calcium (Ca); Calcium levels remain relatively high across all samples with the control at 33.59% and a slight decrease in MS80 to 23.45%. This high calcium presence shows that cement remains as the source of calcium with slag added to it. Calcium role, in forming C-S-H ensures strength development across all samples [22].

Silicon (Si); The silicon content varies significantly reaching its peak at 43.16% in MS60 compared to 20.62% in the control sample. This increase in silicon indicates a higher silica content in the slag, which contributes to the formation of more C-S-H thereby enhancing the strength and durability of the material [22].

Antimony (Sb); The levels of antimony remain consistently high across all samples in including the control sample (31.24%). The presence of antimony throughout indicates its source from the cement. Magnesium, aluminium, sulphur, potassium, iron, molybdenum, tin and iodine are the trace elements found in small amounts.

4. Conclusions

This research explored the viability of using manganese slag as sand replacement in the making cement bricks. A thorough assessment was conducted covering factors like compressive strength, flexural strength, water absorption, density and detailed analysis of the microstructure using SEM and EDS techniques. The results offer insights into the feasibility. Performance implications of integrating manganese slag into cement-based materials focusing on both mechanical properties and environmental sustainability.

SEM analysis confirmed that using slag resulted in more noticeable microstructure with gaps as the higher percentage of manganese slag incorporated in the modified brick.

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